# IMPLEMENTATION OF A MASS BALANCE APPROACH TO PREDICTING NUTRIENT FATE OF MANURE FROM BEEF CATTLE FEEDLOTS

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**ABSTRACT.** *Livestock waste management decisions involve inputs from animal nutrition, animal physiology, soil science, meteorology, systems engineering, and environmental engineering disciplines. Each discipline contributes to the complete picture of a waste management system, but none provides a comprehensive description of the waste management problem. Many of the processes are not completely understood and there is a great deal of variability under real world conditions. Useful management decisions may not require sophisticated modeling of each process or even most of the processes. Rather, providing general values and trends to the producer and other potential users gives insight of the overall operation with opportunity to adjust as needed. This article considers the task of a generalized waste management framework that tracks the fate of nitrogen (N) and phosphorus (P) based on the SCS Agricultural Waste Management Handbook (Krider et al.,1992). A model (available on diskette from the authors) has been implemented using Visual Basic (Microsoft Corp.) to provide a convenient user interface. Discussion is based on a cattle feedlot waste management system, but the component analysis process would apply to other species as well. The system described here is implemented in code; yet, it accommodates refinements as information becomes available.*

***Keywords.*** *Model, Waste management, Nitrogen, Phosphorus.*

A livestock producer is faced with many decisions each year, such as deciding when to purchase animals, what ration to feed, tactical management adjustments to counter the weather, when to sell, and a range of animal health and welfare issues. Cattle feedlot managers often produce grain as well, with additional decisions such as planting, tillage, fertilizer, irrigation scheduling, and other production related tasks. Expediency often dictates choices of convenience for waste management (the nearest field generally gets the most manure) or no decision at all until a problem occurs. Engel et al. (1990) pointed out the need for expertise in many domains to be an effective and efficient producer. Access to information relevant to the decisions and expertise in the manure management decision process is often difficult if not impossible to achieve.

Schulte et al. (1994) noted that much technical information exists on the design and evaluation of manure management systems, and modeling and operational tools are available for evaluating various components of manure management systems. Building on that technical information base, this report utilizes the *SCS Agriculture Waste Management Field Handbook* (Krider et al., 1992) as a basis for design and implementation of a waste management system model. The generalized waste management system schematic (fig. 1) is based on what will hereafter be referred to as the SCS Handbook. Figure 1 illustrates the elements and potential complexity of such systems involving biological, physical or environmental processes that occur over time and distance.

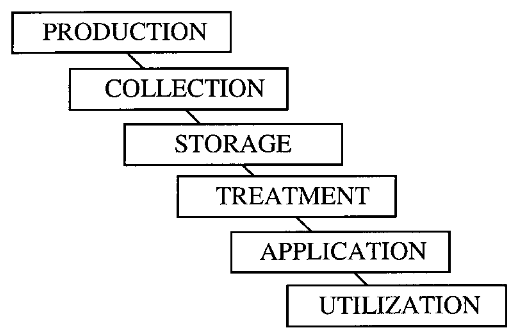


**Figure 1–Generalized waste management system.**

## PURPOSE AND METHODS

The purpose of this work is to combine nutrient loss information related to feedlot cattle operations into a descriptive model that can be useful to producers and researchers. The implementation of this mass balance nutrient fate model, initially developed by Eigenberg et al. (1995), tracks nitrogen (N) and (P) through each of the system components (fig. 2) in both liquid and solid phase. The SCS Handbook describes the major constituents of animal waste as carbon, N, P and potassium. Of these only N and P are considered as potential contaminants. The

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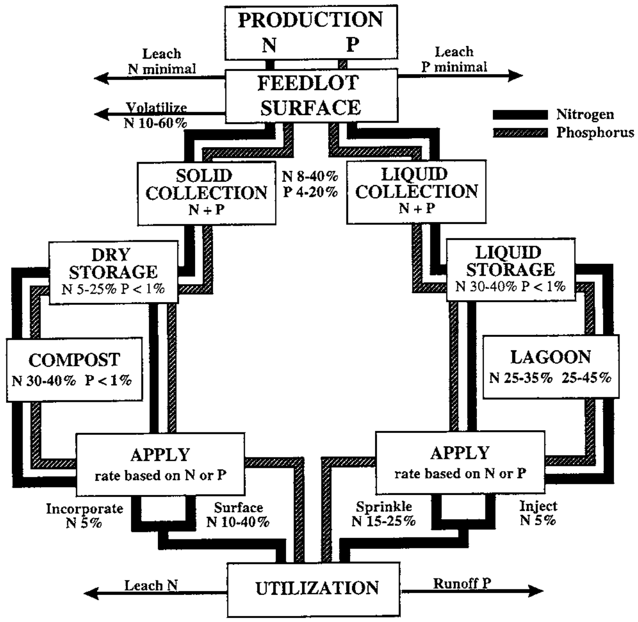


**Figure 2–Nutrient fate flow diagram.**

following are noteworthy in the development of the mass balance model:

- Visual Basic has been used to provide a convenient interface and offers compiled runtime capability so that the end user does not require the host application to run the program. Visual Basic runs faster in comparison to a spreadsheet implementation and is easier to maintain.
- Seasonal loss values are based on sources which include the SCS handbook. The time basis for nutrient losses are included where available.
- The seasonal losses are applied to each season based on the amount of nutrient available in that season; for example the loss of N in manure that has been in storage for two seasons will be computed based on the remainder after two seasons of loss and based on the anticipated loss for the current season.
- Where appropriate, losses are expressed as percentages and equation inputs and calculations are in pounds for the convenience of end-users.
- The processes that govern the nutrient losses are highly variable; as such results of the model's operation are only estimates based on best available sources. Outputs provide an estimate for a manure management system; significant season-to-season and site-to-site variability is expected.
- The model has the capacity to be 'fine-tuned' by the user as information becomes available and so may be adapted to specific areas and management practices.

The following sections describe the implementation of the mass balance model components as depicted in figure 2.

# Manure Production

## Nutrient Production at the Feedlot

The SCS Handbook provides tabular estimates of beef cattle wastes as excreted for three weight ranges and two diet types. The values from this source do not provide seasonal adjustments for manure production. This information can be supplied in the user-editable table if the user has seasonal corrections for manure production.

## Manure Production — Model Implementation

The mass balance method begins with estimates of waste generation as P, N, and DM (dry matter). Waste generation is potentially affected by climatic conditions, and is therefore calculated on a basis of four, 91-day seasons. The production values for a season are determined as follows:

$$\left( \sum_{T=1}^{n} AnWt_T \times AnNum_T \times PrdRate_T \times Time \right)_s \quad (1)$$

where

| | | |
|---|---|---|
| $MatProd_S$ | = | N, P, or DM production total for the season (S) |
| $AnWt_T$ | = | average weight of the animal type during season (lb) |
| $AnNum_T$ | = | number of head of the type of animal |
| $PrdRate_T$ | = | rate of material production for type (lb/animal lb/day) |
| Time | = | based on a 91-day duration of each season (day) |
| S | = | seasonal subscript denoting season of origin |
| T | = | type subscript denoting diet and animal type |
| n | = | number of animal types and diet combinations |

The production mass balance values are supplied as program default values for $PrdRate_T$ and are listed in table 1. These default values are in terms of waste produced per day per pound of animal weight, so the tabular values are the same if metric units are used. The default values supplied to the program from a user editable text file (fig. 5) are used to develop the production values as determined by equation 1. The production step implements equation 1 in a form which allows herd data to be input for each of the four seasons. The user is able to input animal numbers and average weights for three categories: (1) fed cattle 340 to 450 kg (750-1000 lb) with a high (high concentrate) and a low (high forage) energy ration available; (2) calves 200 to 340 kg (450-750 lb); and (3) cows.

**Table 1. Nutrient and dry matter production rates for manure**

| Type (T) | N | P | DM |
|---|---|---|---|
| Feeders, HI* | 0.00030 | 0.000094 | 0.00594 |
| Calves, HI | 0.00030 | 0.00010 | 0.00757 |
| Cows, HI | 0.00033 | 0.00012 | 0.00731 |
| Feeders, LO* | 0.00031 | 0.00011 | 0.00686 |
| Calves, LO | 0.00030 | 0.00010 | 0.00757 |
| Cows, LO | 0.00033 | 0.00012 | 0.00731 |

* HI (high concentrate), LO (high roughage). [PrdRate (eq. 1), lb/lb of animal/day]

# Manure Collection

## Collection Nutrient Fate

Hutchison et al. (1982) reported that ammonia flux density from a Colorado feedlot represented about one-half of the total N deposition in urine or about one-fourth the rate of the total N deposition. This study showed an approximate 3.7:1 flux rate change for environmental change from very hot conditions to cool wet conditions. Adriano et al. (1971) found that nearly 50% of total N was lost from simulated feedlot surfaces during a 10 week study, which was consistent with their measurement of N loss of 40% of total N from corrals. Power et al. (1994) reported that little N may be lost with daily temperatures below 5°C, but 40 to 60% of total manural N can be lost through ammonia volatilization between 5° and 25°C.

**FEEDLOT Phosphorus Losses.** Phosphorus movement from the open feedlot occurs in sediment transported from the feedlot. Gilbertson et al. (1970) found that P transport was not affected by stocking rate or feedlot slope as a result of rainfall-runoff. However, winter conditions caused four to seven times higher P runoff than summer. Leaching is also considered negligible for P in an open feedlot situation due to the assumed sealing of the feedlot surface (SCS Handbook).

**Composition and Mass.** The SCS Handbook has tabulated values for typical beef waste, as removed from both paved and unpaved open feedlots. Variation in livestock waste characterization results largely from the uncertain and unpredictable additions to and losses from the “as excreted” manure. Collection systems and environment will impact the composition and mass of the manure product. A feedlot scrape and haul operation will pick up variable amounts of soil with the manure depending on the working conditions within the lot. Eghball and Power (1994) reported ash contents of 70% in manure scraped from feedlots in 1993, and 59% in 1992, illustrating the variability in composition of manure from an outdoor feedlot. Power et al. (1994) state that manure removed from the feedlot is commonly mixed with 50% or more soil; this composition change is reflected in table 2a.

**Nitrogen and Phosphorus Runoff.** Collection systems generally provide minimal opportunity for nutrient flow out of the system as this step provides short term conveyance with minimal environmental contact. Volatile solid measurements indicate that about 4% of the total volatile solids are contained in precipitation runoff in the summer and about 20% in the winter (Gilbertson et al., 1970). Based on the N:P ratio of the runoff material (Gilbertson et al., 1970) compared to the N:P ratio of fresh manure an estimated 8% (of total N) is diverted to liquid runoff in the summer and 40% in the winter. The fraction of P flowing to the liquid collection system is expected to track the percentages of volatile solids with P percentages of about 4% of the total under unfrozen conditions to an estimated 20% in the winter. Table 2b lists the collection split percentage values for liquid and solid material coming from the feedlot.

**Table 2a. Surface loss factor for collection [$MSurfLoss_S$ (eq. 2), %]**

| Season (S) | N | P | $DM_{added}$ |
|---|---|---|---|
| Spring | 40* | 0 | –50 |
| Summer | 60* | 0 | –50 |
| Fall | 40* | 0 | –50 |
| Winter | 10* | 0 | –50 |

**Table 2b. Collection material split between liquid and solid [$MSys_S$ (eq. 2), %]**

| Season (S) | $N_{solid}$ | $P_{solid}$ | $DM_{solid}$ | $N_{liquid}$ | $P_{liquid}$ | $DM_{liquid}$ |
|---|---|---|---|---|---|---|
| Spring | 60* | 80* | 90 | 40 | 20 | 10 |
| Summer | 92* | 96* | 90 | 8 | 4 | 10 |
| Fall | 92* | 96* | 90 | 8 | 4 | 10 |
| Winter | 60* | 80* | 90 | 40 | 20 | 10 |

* Loss values reflect seasonal effects within range of values specified in literature.

## Manure Collection — Model Implementation

The collection portion of code considers four factors: (1) the diversion of the solid/liquid fraction into the two waste handling systems; (2) the addition of soil to both the liquid and solid fractions; (3) the loss that occurred before collection from the feedlot surface; and (4) the season of the year. The model is functionally dependent on choice of collection times by the user. Collection can occur in any or all of the four seasons. The appropriate equations are chosen based on the user definition of the feedlot operation. Solid and liquid mass balance response is handled by the same equations.

For collection at end of season of generation:

$$MColl_{S,0} = MProd_S \times (1 - MSurLoss_S) \times MSys_S \quad (2a)$$

For collection at end of one season beyond season of generation:

$$MColl_{S,1} = MColl_{S,0} + MProd_{S+1} \times (1 - MSurLoss_{S+1}) \times MSys_{S+1} \quad (2b)$$

For collection at end of two seasons beyond season of generation:

$$MColl_{S,2} = MColl_{S,1} + MProd_{S+2} \times (1 - MSurLoss_{S+2}) \times MSys_{S+2} \quad (2c)$$

For collection at end of three season beyond season of generation:

$$MColl_{S,3} = MColl_{S,2} + MProd_{S+3} \times (1 - MSurLoss_{S+3}) \times MSys_{S+3} \quad (2d)$$

where

$MColl_{S,n}$ = N, P, or DM accumulated as solid or liquid either on lot surface or in a holding pond through season S with associated accumulations and losses through n seasons beyond S

$MProd_S$ = material produced as in equation 1 for season S

$MSurLoss_{S+n}$ = fractional material loss/gain from feedlot surface for season n beyond season of origin (S).

$MSys_{S+n}$ = fractional material diverted to either solid or liquid system for season S + n
S = season of origin of nutrients
n = seasons beyond season of origin

The collection mass balance values are supplied as program default values for $MSurLoss_S$ and for $MSys_S$ which are listed in tables 2a and 2b. Table 2a provides the surface loss factors; these user modifiable values are in percentages and reflect feedlot surface losses of N and P and dry matter gain for each of the four seasons. Table 2b contains the factors for splitting the nutrients retained as solids on the feedlot surface and nutrients contained in precipitation runoff from the feedlot for each season. The default values of tables 2a and 2b are supplied to the program as a user-editable text file (fig. 5). Selection of collection season/seasons determines how long the nutrients are on the feedlot surface; losses are cumulative for the period from season of production until season of collection.

## Manure Storage

### Storage Nutrient Fate

**STORAGE Nitrogen Loss.** A typical feedlot waste storage method is a dry stack from the scrape and haul process, with liquid retained in ponds from precipitation runoff leaving the feedlot. While storage implies no chemical, biological, or physical changes, such changes do occur in reality, and they must be addressed in the nutrient flow model. Estimates of up to 25% loss of N due to volatilization were given by Power et al. (1994) for waste stored in a dry stack awaiting application on the field or use in a composting operation.

For liquid storage, Sweeten and Wolfe (1994) found that well maintained settling basins remove a high percentage of settleable constituents. The Texas study showed a Total N removal efficiency of 14 to 24%. Culley and Phillips observed that liquid storage facilities can lose approximately 33% of the N by volatilization.

**STORAGE Phosphorus Loss.** Sweeten and Wolfe (1994) found that properly sized and operated settling basins remove a high percentage of settleable solids but performance varied widely over time and between systems with an average total P loss less than 2%. Eghball and Power (1994) found minimal loss in P during composting of feedlot manure and a similar loss factor may be anticipated for manure kept in dry stack storage. Table 3 summarizes the material losses for the storage process.

### Manure Storage — Model Implementation

The mass that is collected in either solid or liquid form can be put in storage with the appropriate modification to composition as described above. The model has provision for storage increments of 0, 3, 6, or 9 months. The mass balance relations for the storage components:

For no storage (zero days):

$$MStor_{S,0} = MColl_{S,n} \quad (3a)$$

For one season of storage (91 days):

$$MStor_{S,1} = MStor_{S,0} \times (1 - MStorLoss_{S+1}) \quad (3b)$$

For two seasons of storage (182 days):

$$MStor_{S,2} = MStor_{S,1} \times (1 - MStorLoss_{S+2}) \quad (3c)$$

For three seasons of storage (273 days):

$$MStor_{s,3} = MStor_{S,2} \times (1 - MStorLoss_{S+3}) \quad (3d)$$

where
$MStor_{S,n}$ = N, P, or DM available per season from storage
$MColl_{S,n}$ = N, P, or DM per season from collection (eq. 2)
$MStorLoss_{S+n}$ = N, P, DM fractional per season loss due to storage
S = season of origin of nutrients
n = seasons beyond season of origin

The storage mass balance losses are supplied as program default values for $MStorLoss_S$ and are listed in table 3. The user is also able to select the time in storage from zero to three seasons with multiple seasons having accumulated losses. The user modifiable (fig. 5) loss figures give material losses for each of the four seasons.

**Table 3. Material loss in storage [$MStorLoss_S$ (eq. 3),%]**

| Season (S) | $N_{solid}$ | $P_{solid}$ | $DM_{solid}$ | $N_{liquid}$ | $P_{liquid}$ | $DM_{liquid}$ |
|---|---|---|---|---|---|---|
| Spring | 10* | 0 | 0 | 15* | 2 | 0 |
| Summer | 25* | 0 | 0 | 30* | 2 | 0 |
| Fall | 20* | 0 | 0 | 30* | 2 | 0 |
| Winter | 5* | 0 | 0 | 15* | 2 | 0 |

* Loss values reflect seasonal effects within range of values specified in literature.

## Manure Treatment

### Treatment Nutrient Fate

**TREATMENT Nitrogen Loss.** Treatment can take on various forms ranging from digesters to composting. The most common forms of treatment for feedlot cattle wastes are composting for the solids and lagoons being a possibility for liquids. Composting the solid manure removed by the scrape and haul process results in nutrient loss; this has been measured and reported by Eghball and Power (1994) to range between 20% and 40% of the incoming N over a 110-day period, with the loss due primarily to volatilization.

Liquid treatment occurs in lagoons designed for biological treatment of animal waste as compared to storage ponds which are designed for temporary storage of animal waste (Parker et al.,1994). Anaerobic lagoons are widely accepted as a method of animal waste treatment of liquid waste and can be applied to feedlots systems. The reduction of nutrients for a single stage of a two lagoon system (for dairies in Texas) had N reductions about 25 to 35% based on hydraulic retention times of 81 to 118 days (Sweeten and Wolfe, 1994).

**TREATMENT Phosphorus Loss.** The P loss due to treatment by composting was found to be small (Eghball and Power, 1994) and due entirely to runoff from the compost piles. For liquid runoff, the two lagoon systems studied by Sweeten and Wolfe (1994) resulted in total P reductions of approximately 25 to 45% for one stage of a two stage lagoon system as measured in the effluent for hydraulic retention times of 81 to 118 days. There is an apparent loss of P in the liquid form due to settling but the P remains in the sediment of the storage pond. This must be dealt with when the facility is cleaned.

**TREATMENT Dry Matter Loss.** Bio-oxidation in composting and lagoon treatment processes can result in significant reduction in volatile solids and in total solid amounts. Eghball et al. (1997) found that composting reduced total mass by 15 to 20% during a 110-day study. Lagoons have the capability of reducing total solids by as much as 25 to 60% (Sweeten and Wolfe, 1994) as measured in the effluent with hydraulic retention times of 81 to 118 days. The material loss factors for the treatment step are listed in table 4.

### Treatment — Model Implementation

Materials collected in either solid or liquid form can be stored or transferred to treatment directly (zero storage time) with the appropriate modification to composition as described above. The model has provision for treatment period increments of 0, 3, 6, or 9 months. The mass balance relations for the treatment components are nearly identical to the storage step.

For no treatment (zero days):

$$MTrmt_{S,0} = MStor_{S,n} \quad (4a)$$

Or if there is no treatment (zero days):

$$MTrmt_{S,0} = MColl_{S,n} \quad (4b)$$

For one season of treatment (91 days):

$$MTrmt_{S,1} = MTrmt_{S,0} \times (1 - MTrmtLoss_{s+1}) \quad (4c)$$

For two seasons of treatment (182 days):

$$MTrmt_{S,2} = MTrmt_{S,1} \times (1 - MTrmtLoss_{S+2}) \quad (4d)$$

For three seasons of treatment (273 days):

$$MTrmt_{S,3} = MTrmt_{S,2} \times (1 - MTrmtLoss_{S+3}) \quad (4e)$$

where

$MTrmt_{S,n}$ = N, P, or DM available per season from treatment

$MStor_{S,n}$ = N, P, or DM available per season from storage (eq. 3a-d)

$MTrmtLoss_{S+n}$ = N, P, DM fractional per season loss due to treatment

S = season of origin of nutrients

n = seasons beyond season of origin

The treatment mass balance values are supplied as program default values for $MTrmtLoss_S$ and are listed in table 4. These user modifiable (fig. 5) percent loss values provide material losses for composting for the solid side and for liquid treatment for each of the four seasons. The user can select the number of seasons in treatment with the multiple seasons exhibiting cumulative losses.

**Table 4. Material loss in treatment [$MTrmtLoss_S$ (eq. 4),%]**

| Season (S) | $N_{solid}$ | $P_{solid}$ | $DM_{solid}$ | $N_{liquid}$ | $P_{liquid}$ | $DM_{liquid}$ |
|---|---|---|---|---|---|---|
| Spring | 20* | 0 | 15 | 25* | 25* | 25 |
| Summer | 40* | 0 | 20 | 35* | 45* | 60 |
| Fall | 40* | 0 | 20 | 35* | 45* | 60 |
| Winter | 20* | 0 | 15 | 25* | 25* | 25 |

* Loss values reflect seasonal effects within range of values specified in literature.

## Manure Application

### Application Nutrient Fate

**APPLICATION Nitrogen Loss.** The application rate for manure is dependent on nutrient content of manure, field soil nutrient conditions, crop needs, and moisture holding capacity of the soil (for liquid manure). The application method can influence net nutrient availability. Beauchamp (1991) observed that in some cases for solid manure applied to the soil surface more than 50% of ammonia was lost through volatilization in the first day with the potential that almost all ammonia would be lost within two to three weeks. The SCS Handbook gives a range, % N loss, of values for various soil and climatic conditions. Broadcast application of fresh solids to the soil surface caused 0 to 30% N loss after the first day as environmental conditions range from cool, wet to warm, dry conditions. Incorporation results in conservation of N with only about 5% lost. Slurry from liquid storage or a lagoon treatment system loses only 5% of N in injection application but 25% for sprinkler application for the season.

**APPLICATION Phosphorus Loss.** Miller (1991) states that whenever water moves through a soil with a significant nitrate concentration, the soluble nitrate is transported by the water. However, P, being strongly bound by the soil does not leach, but is carried along with eroded soil. Calculations of runoff estimates based on field slopes and tillage practices as modeled by PERFECT (Watts et al., 1994) are given in table 5.

### Application — Model Implementation

The materials that are collected in either solid or liquid form and pass through treatment are available for application. The mass balance relations for the application step are given here:

$$MApp_S = MTrmt_{S,n} \times (1 - MAppLoss_S) \quad (5)$$

where

$MApp_S$ = N, P, or DM per season to apply

$Mtrmt_S$ = N, P, or DM per season from treatment (eq. 4a-d)

$MAppLoss_S$ = N, P, DM fractional per season loss from application

S = season of origin of nutrients

n = seasons beyond season of origin

**Table 5. Material loss in application [$MApplLoss_S$ (eq. 5),%]**

| Season (S) | $N_{broadcast}$ | $N_{incorporate}$ | $N_{sprinkle}$ | $N_{inject}$ |
|---|---|---|---|---|
| Spring | 15* | 5 | 25* | 5 |
| Summer | 40* | 5 | 25* | 5 |
| Fall | 40* | 5 | 25* | 5 |
| Winter | 10* | 5 | 15* | 5 |

* Loss values reflect seasonal effects within range of values specified in literature.

The application mass balance values are supplied as program default values (fig. 5) for $MAppLoss_S$ and are listed in table 5. Actual totals of N and P available are provided in the season that they would be available for application, taking storage and treatment times into consideration. Options for solid manure application include land surface or incorporation; the liquid application alternatives are injection or sprinkler irrigation. The amount of dry matter is displayed to give a value of the magnitude of the material that must be handled, either at the time of application or in the case of liquid systems, when the storage area is cleaned.

## Manure Utilization

Process models are designed to describe the dynamics of the plant growth which are dependent on plant physiology, time and weather inputs, and nutrient uptake curves. A process model such as NEM (Schulte et al., 1994; available on diskette by contacting the authors) partitions organic N into plant growth, surface runoff, mineralization, and infiltration to describe the N balance throughout the growing season. This component would aid producer/growers in integrating the manure handling and crop production. The output of the mass balance model provides necessary nutrient information as an input for the appropriate crop process model. Integration into the model is beyond the scope of this article.

## User Interface

The user interacts with only three screens with this nutrient fate model. The first screen the user will access is the management input screen (fig. 3) where the entire feedlot operation is defined. From this screen the user will enter production values including the average number of cattle of each type for each season and a choice of high or low energy values for the ration in use. Collection is the removal of feedlot waste from the feedlot surface, usually by scraping. The user must choose collection in at least one season but may choose to collect in any combination of seasons that reflect the operation. Changes are made to the screen using the mouse and clicking the desired option buttons. Storage and treatment processes may be scheduled

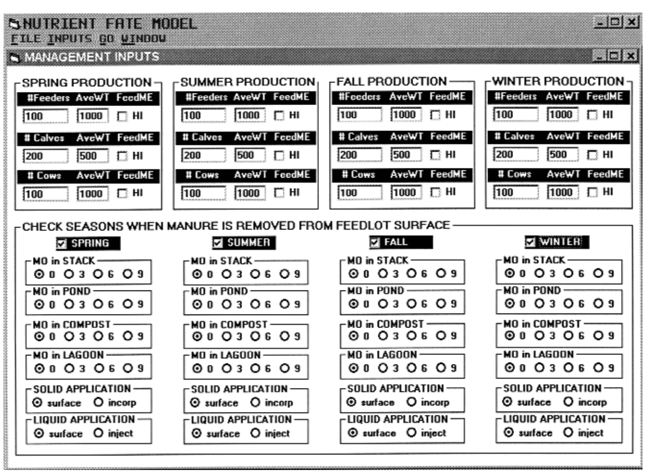


**Figure 3–Management input screen allows user to define animal production facilities as well as seasons of manure collection.**

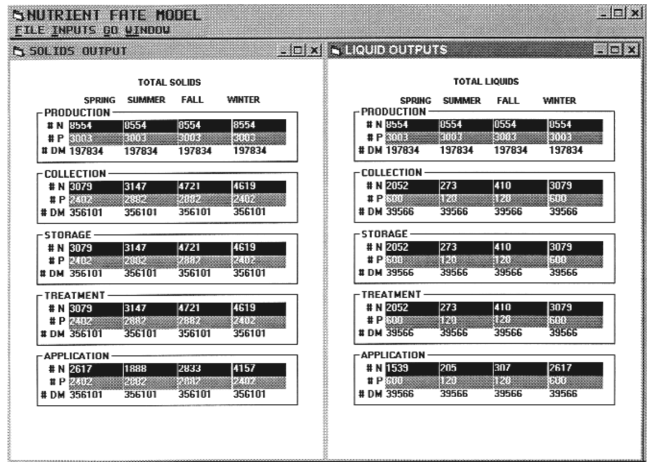


**Figure 4–Output screen displays solid and liquid components of the waste stream. Nutrients and dry matter are split into the solid or liquid fraction at this stage. Totals are shifted on the display screen to account for season of collection, storage, and/or treatment time.**

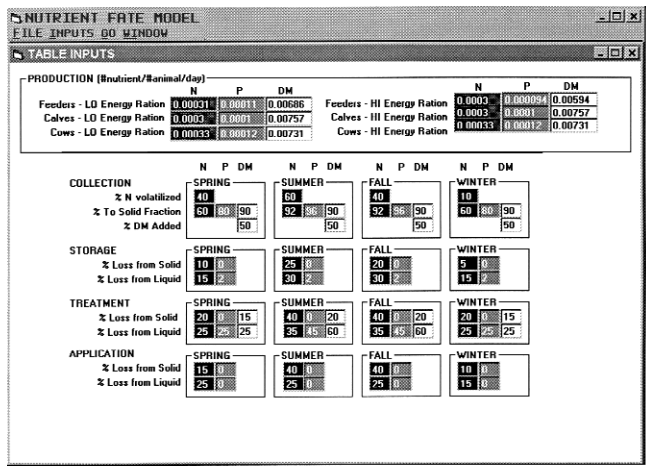


**Figure 5–User editable table containing operational values for all steps of the model operation.**

in any season in which collection takes place, provision is made for the solid and liquid components. The default values are for no storage or treatment. Application choices include surface application and incorporation or injection.

Having set the feedlot management options the user selects the GO command which initiates the calculations and generates the output screen (fig. 4). The output screen displays both the solids and the liquid components of the waste stream for each phase of the waste management process. It is important to note that totals are shifted on the display screen to account for season of collection and storage and/or treatment time. The model assumes a steady-state system (management practices the same from year to year), so nutrients produced this year but not collected or available till next year are wrapped around to the appropriate season.

As noted earlier in this article the user has full access to the mass balance figures as shown in figure 5. The default entries are current best estimates based on current understanding of the processes in a generalized model. A producer/user with more suitable values based on operational characteristics could modify the entries to match that production situation.

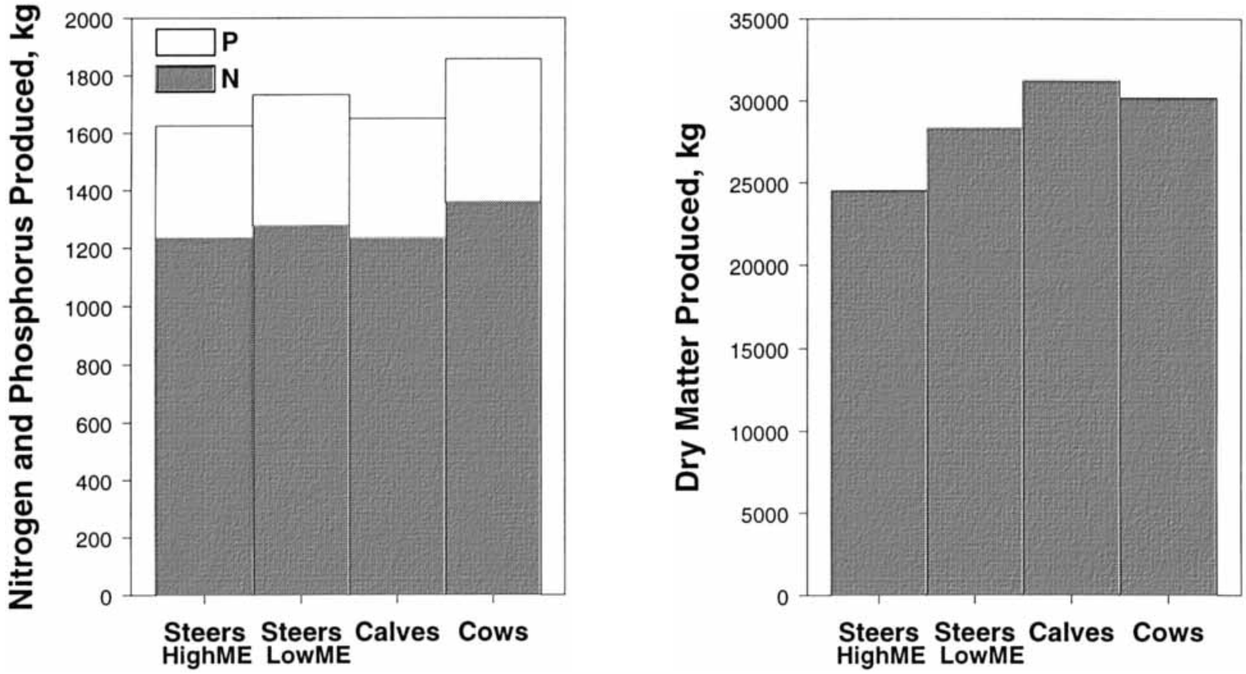


**Figure 6–Nitrogen, phosphorus, and dry matter production by animal type and feed energy (feeders) based on 45 360 kg (100,000 lbs) total animal weight.**

## RESULTS

The model was initially run with the default values in place. Figure 6 shows the production figures for N, P, and DM for fed cattle on high energy and high forage diets as well as for calves and cows. The output shows the production ratio of N to P averages about 3:1. Figure 7 displays the output from the model by season and by waste management step showing the percentage of original N produced remaining at each step of the process. Overall, the season of the year, storage and treatment are seen to have dramatic impacts on the fate of N. Comparing liquid and solid components reveals that the majority of the waste material is handled and delivered in the solid form with seasonal variations in the amounts. A similar plot of the P component (fig. 8) shows that there is very little loss of P in the waste handling system. In the liquid form there is an apparent loss due to settling but the P remains in the sediment of the storage pond and must be dealt with when the facility is cleaned.

## SUMMARY AND IMPLICATIONS

The waste management system for agricultural producers involves complex processes that have temporal and spatial separations as well as multiple chemical, biological, mechanical, meteorological, economic, and environmental components. Figure 2 incorporates schematic elements of each step of the waste management system as it relates to the fate of N and P. Each step of figure 2 has the potential of expansion to much more detailed subsystems. However, software implementation of figure 2 allows evaluation of magnitudes of waste products and prediction of relative quantities at each point in the waste management process.

By bringing together the components of the overall system a framework is defined that is useful for comparing management options and estimating impact of waste management decisions. This same framework can serve to identify the realities of existing system constraints such as potentially large losses of N due to volatilization as the manure is processed through the waste handling system. Accompanying the large N losses is an associated risk of over-application of P by attempting to meet N needs of the crop through manure application. An implementation of a mass balance system tracking both N and P allows relative amounts to be determined and potential risks identified.

Nutrient mass balance provided a basic structure on which an analytical tool was developed to evaluate decision options. While not a mechanistic description of the process, the mass balance approach allows nutrient quantity estimates to be made and allows straightforward corrections as information is available. Finally, the mass balance approach emphasizes the need to quantify composition. The critical point of quantifying the composition is after the storage step and prior to application to the field. Sampling at this point in the process will safeguard against over or under application of N and P as well as establishing nutrient losses from production through storage.

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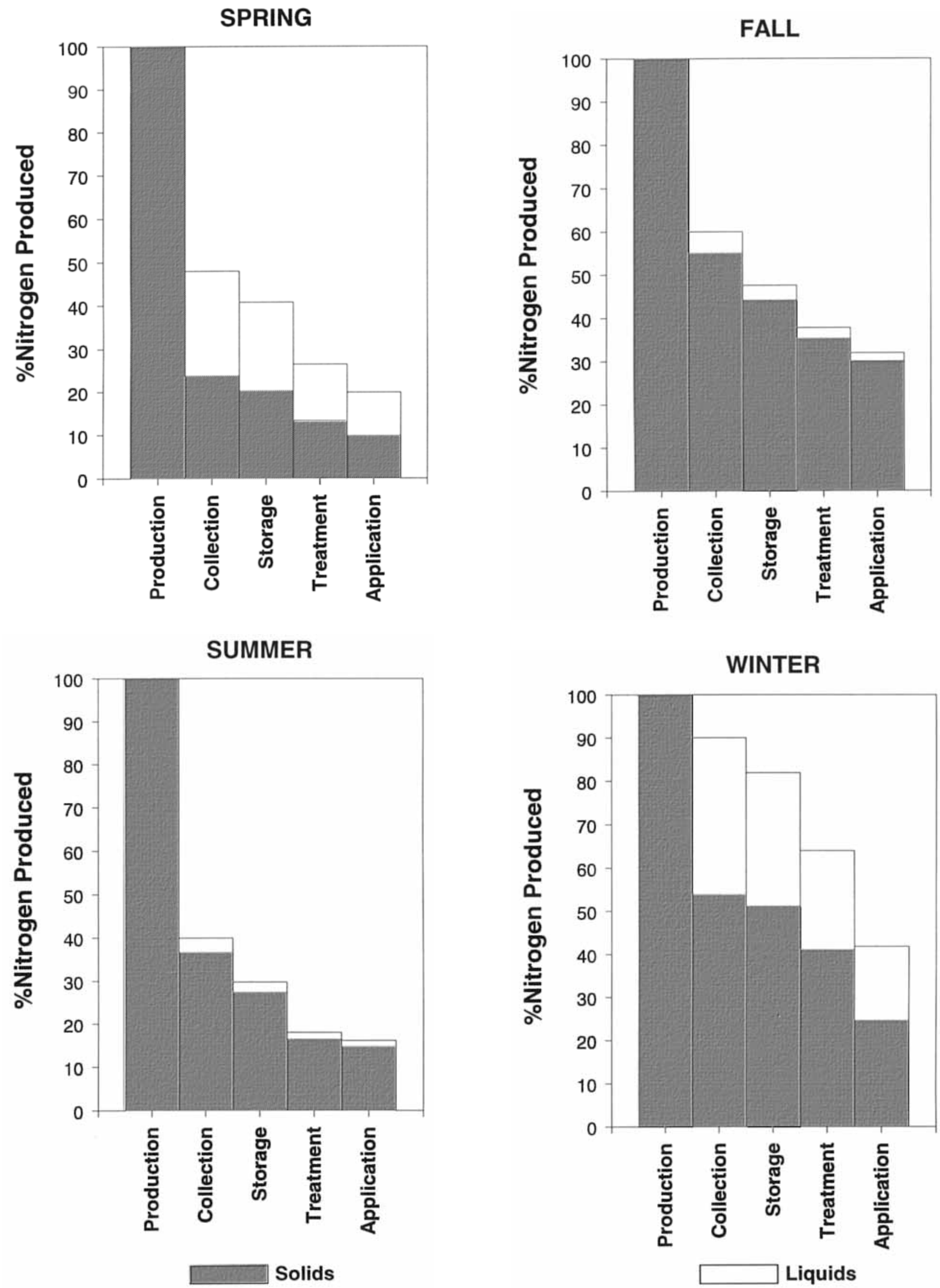


**Figure 7–Waste management steps for remaining nitrogen showing effects of season, storage for one season, and treatment for one season on both liquid and solid waste.**

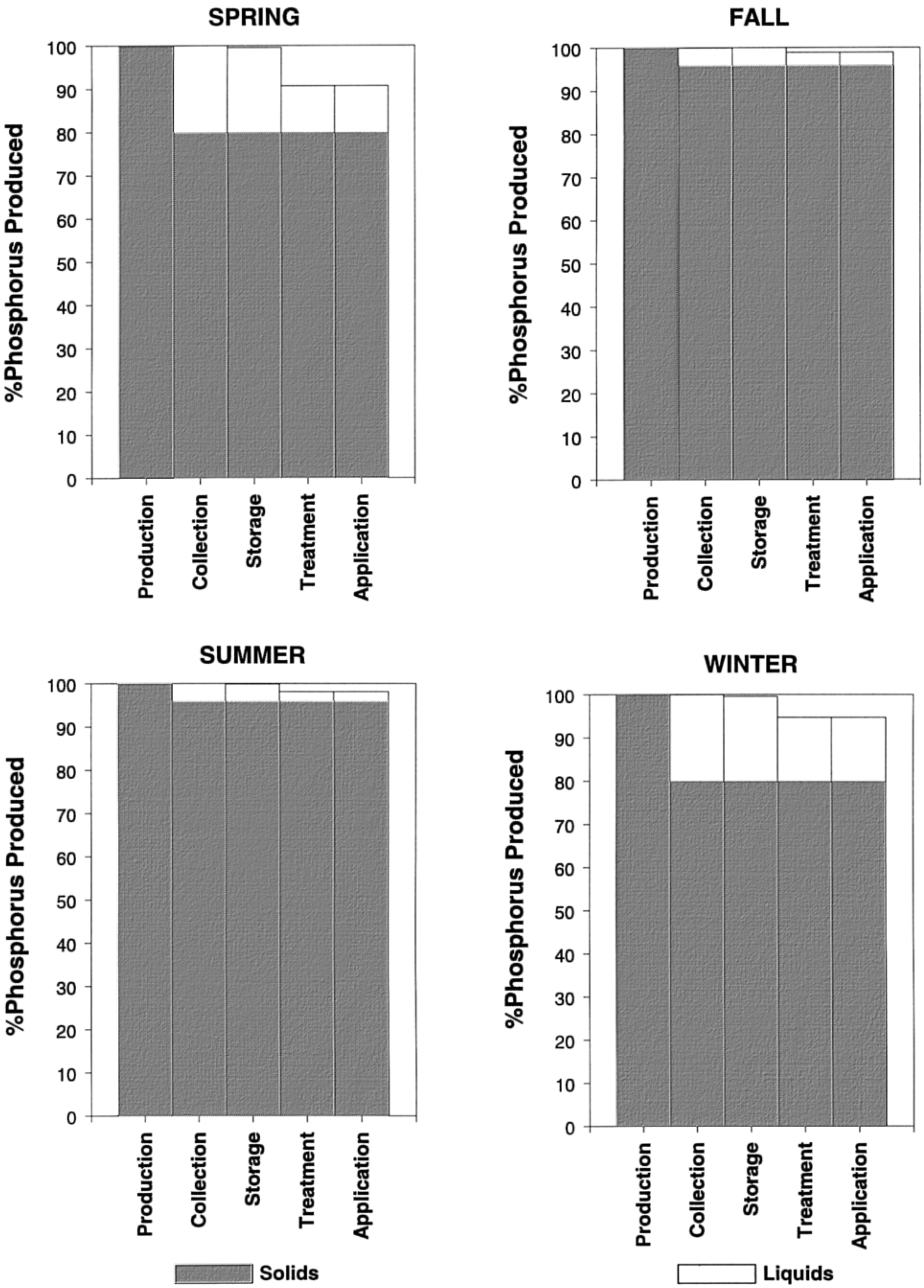


**Figure 8–Waste management steps for remaining phosphorus showing effects of season, storage for one season, and treatment for one season on both liquid and solid waste.**

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